DOCUMENT RESUME

ED 182 562 CE 024 247

AUTHOR	Groseclose, Richard
TITLE	Nuclear Technology. Course 26: Nondestructive Examination (NDE) Techniques I. Module 26-2, Leak Tests.
INSTITUTION	General Physics Corp., Columbia, Md.
SPONS AGENCY	Office of Education (DHEW), Washington, D.C.
PUB DATE	79
CONTRACT	300-77-0340
NOTE	51p.; For related documents see CE 024 245-298
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	Course Content; Energy; Inspection; Learning Activities; Learning Modules; *Nuclear Physics; Postsecondary Education; *Quality Control; Teaching Guides; *Technical Education; *Tests
IDENTIFIERS	Nuclear Energy; Nuclear Energy Occupations; *Nuclear Power Plant Technicians; *Nuclear Technology

ABSTRACT

This second in a series of seven modules for a course titled Nondestructive Examination (NDE) Techniques I describes the predominantly used leak test methods in nuclear power plants. More specifically, the module describes these test methods, the testing techniques, and the associated quality assurance requirements. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

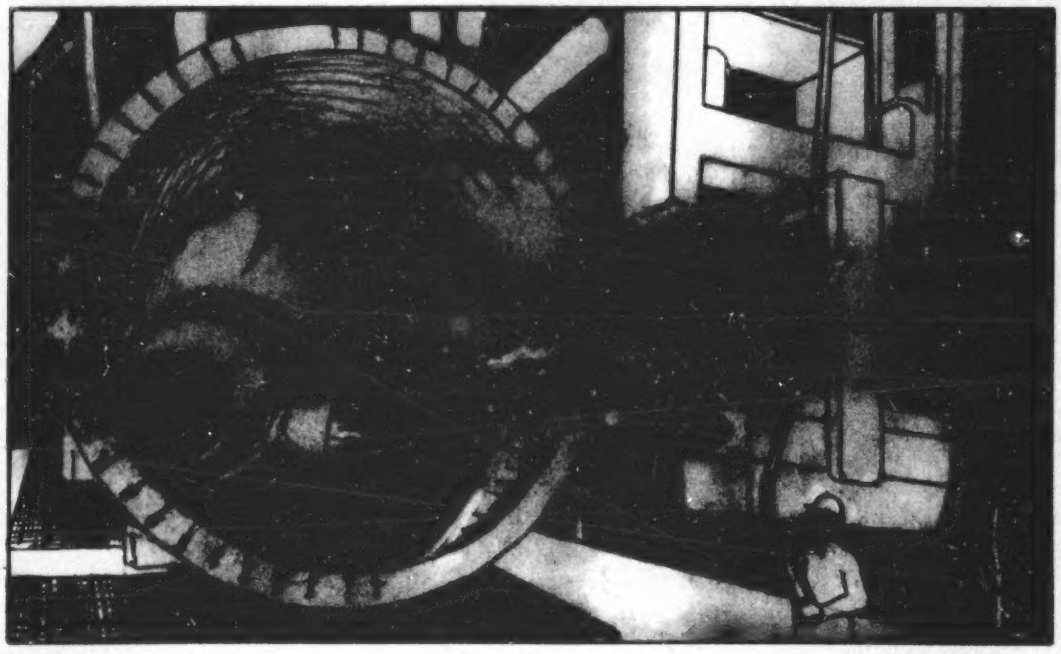
THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

ED182562

NUCLEAR TECHNOLOGY

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

MODULE 26-2 Leak Tests



CE 024 247

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

Module 26-1	Visual Tests
Module 26-2	Leak Tests
Module 26-3	Hydrostatic Tests
Module 26-4	Liquid Penetrant Tests
Module 26-5	Fundamentals of Radiography
Module 26-6	Radiography Inspection
Module 26-7	Radiographic Specifications and Code Requirements

The material in this module was developed by General Physics Corporation under a contract with the United States Department of Health, Education and Welfare, Office of Education, Contract Number 300770340. Contractors undertaking such projects are encouraged to express freely their professional judgment in the conduct of the project. Therefore, points of view or opinions stated do not necessarily represent official Office of Education position or policy.

This module was prepared by Dick Groseclose, General Physics Corporation.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

Leak testing is a nondestructive test for determining the integrity of boundaries in pressurized and evacuating systems. While it can be used to test any fluid system, it is primarily used for testing systems which must either contain pressurized gas or hold a vacuum. It is also widely used for testing sealed components for adequacy of their seal.

With respect to nuclear power plants, certain leak test methods are used predominantly. This module describes these test methods, the testing techniques and the associated quality assurance requirements.

The Nuclear QA/QC Technician may have one or more of the following responsibilities with regard to leak testing:

- qualify as a leak tester and perform leak tests
- monitor the performance of leak tests by others
- review leak test results for compliance with written acceptance criteria
- assist in the planning for leak testing including assisting in the review of leak test procedures.

MODULE PREREQUISITES

Completion of High School level classical physics or general science course.

OBJECTIVES

Upon completion of this module, the student/trainee can do the following:

1. Briefly describe the historical development of leak testing.
2. Define the terms leak, leakage, leak rate, minimum detectable leak and minimum detectable leak rate.
3. Describe why the terms zero leakage and leak-free are inappropriate terms for leak testing.
4. Name three fundamental conditions which promote fluid flow across system boundaries and briefly describe how each condition permits leak testing.
5. Relate the relative sensitivities of the following leak test methods: unaided senses, bubble test, halogen diode detector, helium mass spectrometer and pressure decay leak test.
6. Describe the following leak test methods, include description of test equipment, calibration standards, and test techniques: bubble test, pressure decay test, halogen diode detector test, helium mass spectormeter-probe method, and helium mass spectrometer-hood method.
7. Briefly describe the contributions made by the quality assurance provisions of procedure, personnel qualification, and records in terms of quality of leak testing practices.
8. Demonstrate the ability to perform a leak test.

SUBJECT MATTER

Historical Development

For as long as vessels have been used to hold fluids, leak testing has been employed. Perhaps leak tests can be labeled as the oldest branch of nondestructive examination. Advances in leak testing have been linked with progress in the technology of containment, transport and use of fluids and exclusion of fluids from a given vessel. Despite its practical importance, leak testing has remained until recently largely unrecognized as an independent technical discipline.

Historically, leak detection was initially used for liquid systems, i.e., first water and later for other liquids. The development of closed pressurized distribution systems increased the importance of leak detection. Early forms of leak detection consisted of either visual examination or listening for the sounds of air rushing out of (or into) the system. Later, leaks were detected by observing the change in pressure by using a manometer or pressure gage. In 1885, a U.S. Patent was issued for a submergence test method and in 1934 a patent was issued for a bubble test solution. The earliest use of either of these test methods is not known.

The development of steam power in the late 18th century and continuing through the 19th century and the attendent progress in pressure vessel technology helped to stimulate leak testing technology. Within the 20th centruy, the rise in industrial production and use of hazardous fluids has hastened the development of leak detecting methods which have great sensitivity. The widespread use of closed refrigerant systems has also created a market for simple and reliable detections which are sensitive to halide leaks. Ultrasensitive leak testing methods were not required until the advent of modern vacuum technology which began with the introduction of the rotary air-sealed pump in the late 19th century.

As leak testing has advanced, it has become clear that a "leak free" or "zero leakage" containment is merely a concept. All containment systems leak; therefore, the only rational requirement that can be imposed is that such a system leak at a rate no greater than some maximum allowable rate, as long as it is within the sensitivity of a measuring system.

Terminology

Leak testing has concepts represented by the terms: leak, leakage, leak rate, minimum detectable leak, minimum detectable leak rate and leak test. These terms are defined as follows:

- leak refers to the discontinuity or passage through which a fluid flows or permeates.
- leakage refers to the fluid that has escaped through the leak.
- leak rate is the rate of fluid flow per unit time under given conditions and is normally expressed in units of mass per unit time but may be expressed in units of volume per unit time.
- minimum detectable leak is the smallest leak that can be accurately observed by the test method used.
- minimum detectable leak rate is the smallest amount of leak that can be determined using a specific test method.
- leak test is the method for determining the rate at which a liquid or gas will penetrate from inside a "tight" component or assembly to the outside, or vice versa.

Units of Measurement of Leakage

Several variables affect the leak rate from a given leak. Such variables include mass of the fluid, type of flow and

pressure differential. Mass units are typically used for expressing leak rate in order to have a unit which can easily be correlated with all possible variables. In order to express leak rates in mass units, the product of pressure and volume per unit time is chosen because at a constant temperature the product of pressure and volume is proportional to the mass of the leakage. Thus, the unit of leakage measurement most commonly used is standard atmosphere-cubic centimeter per second, i.e., atm-cm^3/sec.

The standard atmosphere is defined as a pressure of 1,013,250 dynes per square centimeter. It is equal to the pressure exerted by a 760 millimeter (mm) column of mercury at standard gravity. The torr is a unit equal to 1/760 atm or 1 mm of mercury. The torr pressure and liter volume unit is used by some to express leak rate, i.e., torr-liter/second.

Conversion factors associated with these units are given in the Appendix to this module.

Fundamental Test Concepts

If leaks are to be detected, the test method must establish conditions which promote fluid flow through the leak. In addition, the test method must be sensitive to at least one characteristic of the leakage.

Conditions established for promoting fluid flow through leaks are either system at pressure or system at vacuum or a combination of these two. Figure 26-2-1 illustrates these concepts.

In the system at pressure test, the system is pressurized at a pressure greater than the pressure of its surroundings. Leakage occurs from the system to the surroundings. In the system at vacuum test, the system is evacuated to a pressure lower than that of its surroundings. Leakage occurs from the surroundings into the system. In the pressure-vacuum combination test, the system is at some pressure (may be

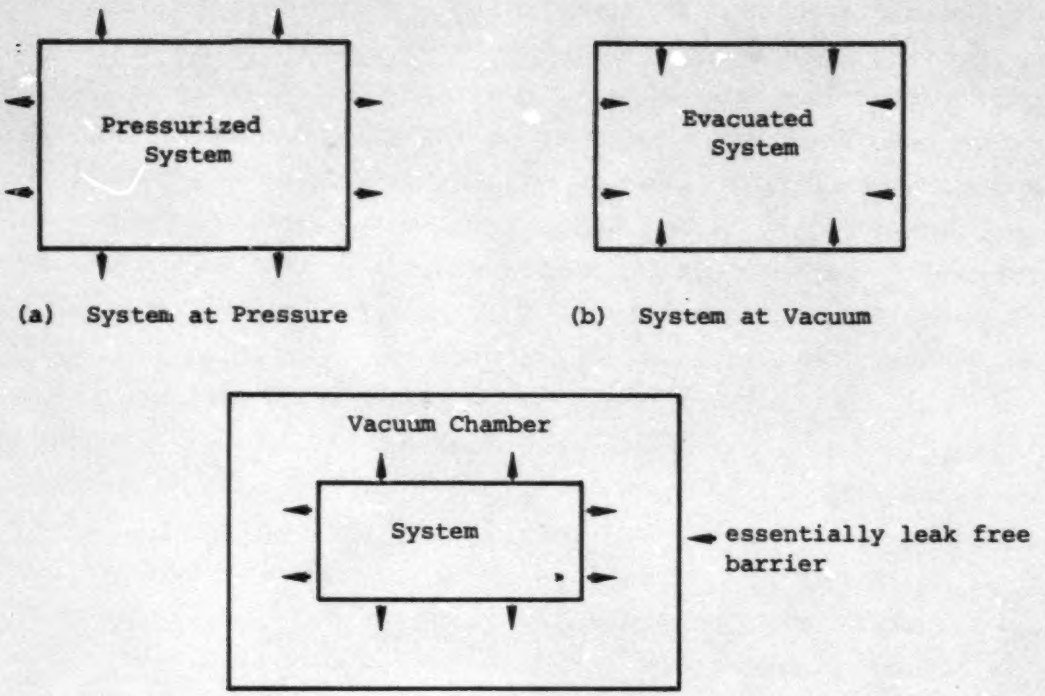


Figure 26-2-1 Leak Test Concepts

atmospheric) and it is surrounded by an artificially created vacuum. The vacuum chamber must have a considerably less leak rate than that of the system. The leakage to be detected flows from the system into the vacuum chamber.

The fluid used as the test medium must be detectable by the test method. For example, if unaided sense of smell is to be used, ammonia would be a good test medium. The specific test media typically used are described later in conjunction with specific test methods.

Reasons for Leak Testing

Leak testing has three basic capabilities: detecting the presence of leaks, measuring leak rates and identifying locations of leaks. As described later in this module, not all leak test methods provide all these capabilities. Some methods can only detect the presence of a leak while other methods possess two or all three capabilities.

Leak testing is specified by engineering specifications and drawings applicable to the manufacture, installation, and operation of power plant equipment. Such tests are specified for individual components and for systems where it is necessary to determine either presence of leaks or leak rate. In general, such tests are specified when it is necessary to accomplish any of the following:

- prevent loss of contents
- prevent contamination of working fluid
- detect unreliable components
- assure maintenance of a pressure differential

Categories of Leak Testing Methods

For ease in understanding leak testing, it is necessary to categorize the methods in use today. There are two broad categories: system at pressure and system at vacuum. The system at pressure category is further categorized by the type of test fluid, i.e., liquid or gas. Finally, gas systems at pressure are categorized as either direct sensing or quantity loss of test methods. Figure 26-2-2 lists the various methods available today.

The test methods used at a nuclear power plant are primarily those for systems at pressure utilizing either the direct sensing gas or liquid leak test methods. The direct sensing gas methods typically used are bubble solution, halogen gas, differential pressure and mass spectrometry.

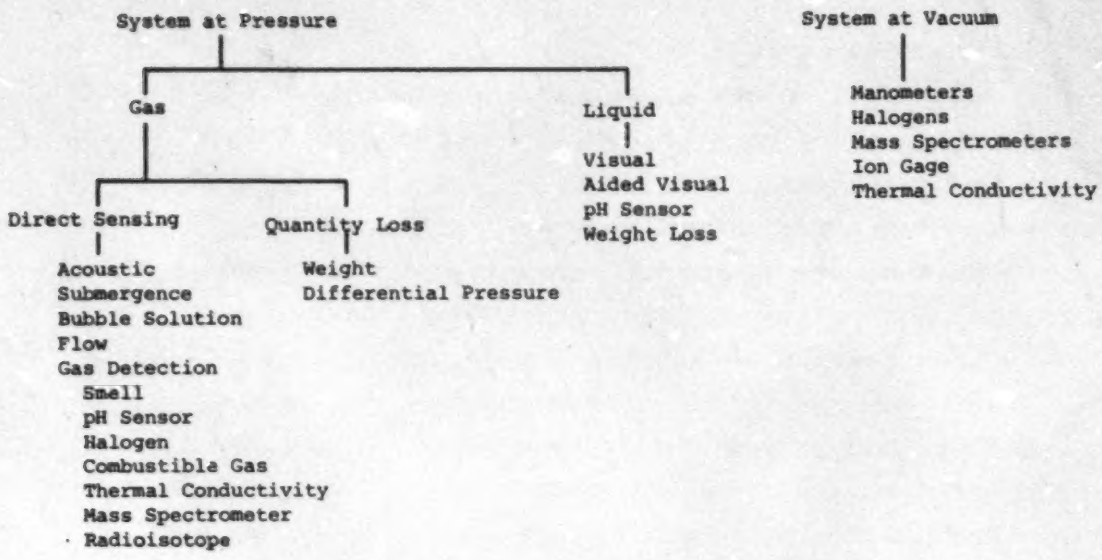


Figure 26-2-2 Leak Test Methods

The liquid test methods used are usually limited to visual leak detection tests. In addition, halogen gas detector and mass spectrometer methods may be used with system at vacuum test. The remainder of the test methods are normally seen in either the manufacturer's test facility or at an independent testing laboratory for the testing of individual components.

Each test method is categorized by sensitivity as high, moderate, or low. Table 26-2-1 lists the relative sensitivities of leak test methods and Figure 26-2-3 illustrates typical sensitivities of various leak test methods.

Table 26-2-1

Relative Sensitivity of Leak Detection Methods and Equipment

Test Method	Relative Sensitivity
Unaided senses Eyes Ears Noes (usual)	Low
Aided senses Bubble solutions/submergence Penetrants Chemical indicators Stethoscopes Combustible gas Halide torch Mass, flow, or pressure change	Moderate
Thermal conductivity Acoustic emission Vacuum gage Halogen detector Ion gage Radioactive isotope Mass spectrometer	High

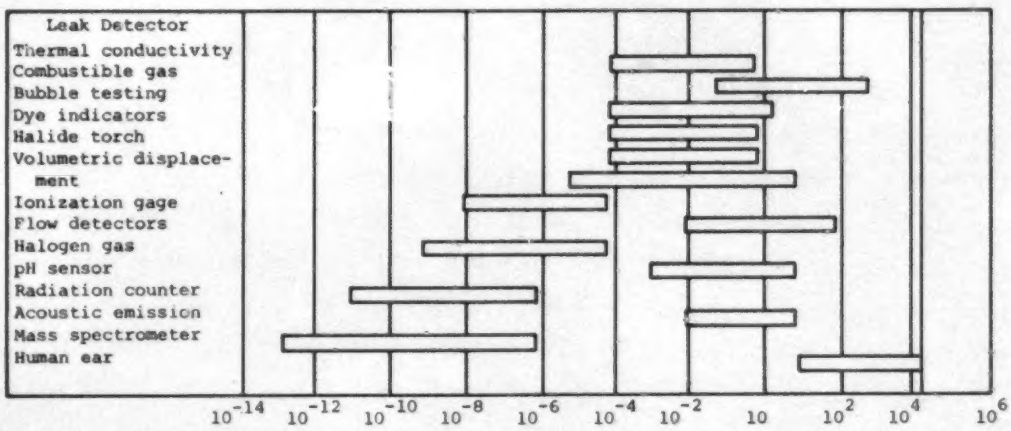


Figure 26-2-3 Sensitivity Ranges

DESCRIPTION OF LEAK TESTING METHODS

As previously indicated, the leak testing methods most commonly used with respect to nuclear power plants are bubble solution, halogen gas detectors, pressure loss, and mass spectrometers. Therefore, this module will concentrate on these test methods. Nonetheless, a brief discussion on the use of unaided senses is appropriate.

The human senses of hearing and smell should be used in conjunction with any leak test. Perhaps you have already experienced detection of natural gas leaks in furnaces, water heaters or pipe lines by smelling the leakage. While some fluids are essentially odorless, human smell can contribute to successful leak testing. Likewise, hearing is important. Many leaks are orificed such that the leakage makes an audible sound as it exits. Detection of leaks by hearing or smell indicates gross leaks because these are low sensitivity tests. In such cases, repairs are probably in order prior to proceeding with the more sensitive test methods.

Bubble Solution

Bubble solution leak testing is a relatively low sensitive test adaptable to system at pressure and pressure-vacuum combination testing. Because soap solutions were originally used for this test, it has been referred to as soap bubble testing. However, soaps and detergents contain elements which can attack the materials of items to be tested and are no longer used. Today's solutions do not contain soap or detergents, and the term soap bubble testing is obsolete.

The test is performed by applying the bubble solution such that the entire test surface is thoroughly wetted. The solution is poured on and not sprayed in order to avoid agitation which of itself may cause bubbles. Leak out of

the pressurized system forms bubbles at the location of the leak. Leak rate is indeterminable with this test method. Either the atmosphere or a gaseous system's working fluid is used as the test medium for the bubble test.

Bubble testing is used where leak rate is not required to be measured. It is frequently used to determine the acceptability of welds in atmospheric and low pressure storage tanks. In this application, the pressure-vacuum combination method is used with the aid of a vacuum box. After applying the bubble solution to the weld, a vacuum box with a clear cover and a sealing material around the bottom edges is placed over the weld. A vacuum pump, connected to the vacuum box by hose and fittings, evacuates the box such that leakage is promoted from the atmospheric side of the weld into the box.

Halogen Gas Detector

The halogen gas detectors are either halogen torch detectors or halogen diode detectors. Each is capable of detecting any of the halogens: fluorine, chlorine, bromine, iodine and astatine.

The halogen (or Halide) torch detector is the oldest type of halogen detector. It has relatively low sensitivity which is essentially the same as that of the bubble test. Figure 26-2-4 illustrates the equipment associated with this test method.

The halogen torch uses a flame heated copper plate for detection. Any of the halogens or halogen compounds drawn through the intake tube by convection reacts with the copper plate. The reaction forms a copper halide which changes the color of the flame.

Halogen torches are mostly used for the detection of leaks and their location in refrigeration and air-conditioning units. It is not effective for measuring leak rate. It is

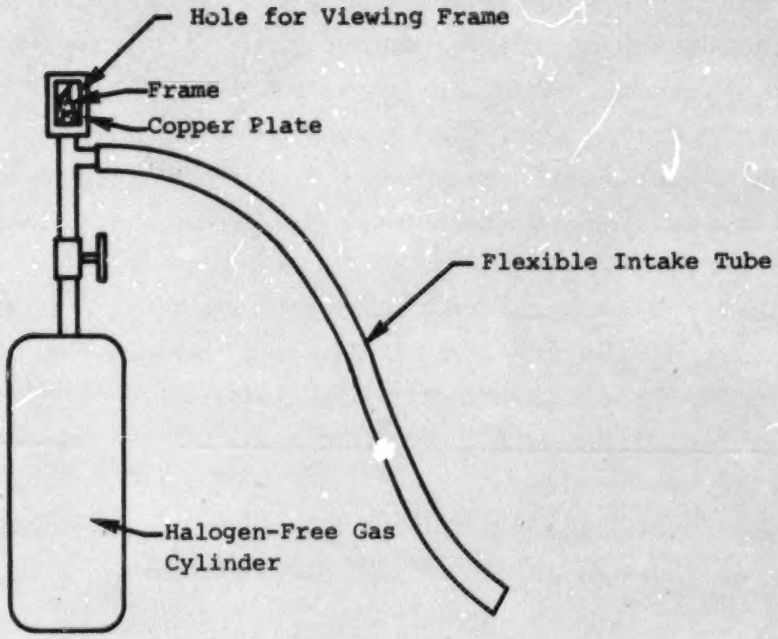


Figure 26-2-4 Halogen Torch

inexpensive, portable and simple to operate. Its disadvantages are that it cannot be used in an explosive atmosphere and, because refrigerant is heavier than air and tends to form in pockets, detection of location of leaks is difficult.

The hot-anode halogen leak detector (halogen diode) has a relatively high sensitivity. It is comprised of a probe and electronic circuitry as illustrated in Figure 26-2-5.

The detector contains a hot platinum or ceramic electrode which readily ionizes halogen atoms. This ionization produces a current between the anode and cathode of the detector. In the presence of halogen vapors, the rate of ionization is proportional to the concentration of halogen present. The electronic circuitry detects the current and displays if on the meter in units of leak rate. The hot-anode halogen detector offers the three capabilities of leak

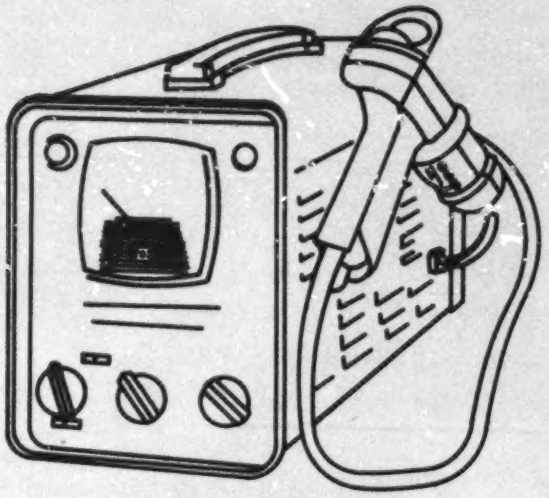


Figure 26-2-5 Hot Anode Halogen Leak Detector

detection, leak location and leak rate measurement. Its chief drawback is that halogen gases are difficult to use as tracer gases because they are generally heavy and have low diffusion rates.

Pressure Loss Leak Tests

Pressure loss (decay) leak testing is a moderately sensitive test method which includes the absolute pressure test and the differential pressure test. Absolute pressure testing monitors the pressure of a system. Pressure loss from the system without apparent cause is indicative of leakage. Differential pressure testing compares the pressure of a system with that of a reference system known to have extremely low leakage. Pressure loss from the system under test is indicated by an increased differential pressure between it and the reference system. Both tests rely on ideal gas laws.

The state of an ideal gas is expressed by the following equation:

$$PV = NRT$$

Where:

P = gas pressure
V = volume of the container of the gas
N = number of moles of gas
R = the universal gas constant
T = absolute temperature of the gas

Consider a system which is pressurized with gas to pressure B, at a temperature of T, and allowed to stand for a time period. At the end of the time period, the pressure is found to have dropped to P_2. If the temperature has not dropped and if it can be assumed that the volume has not increased, the pressure drop must be due to leakage. If the quantity of gas does not change, it follows from the earlier equation that the change in pressure must satisfy the relation:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

If $V_1 = V_2$, as assumed, then the relation becomes:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \qquad \text{(V, N, and R constant)}$$

Measurement of pressure and temperature of the system permits calculation to determine the presence of leaks. If P_2 is found to be in proportion to a drop in temperature, the system has not leaked at a discernable rate. But, if P_2 has decreased beyond proportion to any drop in temperature, leaks must exist. The amount of leakage is ΔN which is expressed by the following equation.

$$\Delta N = N_1 - N_2 = \frac{P_1}{T_1} - \frac{P_2}{T_2} \quad \frac{V}{R}$$

Leak rate is calculated by converting ΔN to mass and dividing by the time elapsed between measurements of P_1, T_1 and P_2, T_2. The mass is found by multiplying the gram-molecular weight of the gas times ΔN.

Water vapor in the test medium can seriously affect leak testing results if condensation occurs. "Dry" gas is used where possible. For example, if air is used as the test medium, the compressed air is passed through moisture separators prior to discharging the air into the system to be tested. Nonetheless, some moisture content is always present.

Condensation of water vapor is avoided by preventing the temperature of the system from reaching the dew point. If the dew point is reached, condensation occurs and pressure decay results from the change in volume. As previously indicated, volume was assumed to be constant in the pressure decay formulas used for leak testing.

Due to the concern with moisture condensation, pressure decay leak testing must include determination of dew point temperature and checks to ensure the dew point is not reached at any time during the test. Dew point temperature may be determined by use of psychrometers or hygrometers. The

psychrometer consists of wet bulb and dry bulb thermometers. The wet bulb temperature is the dew point temperature. Hygrometers are instruments which give direct readout in either relative humidity (%) or dew point temperature. When relative humidity is indicated, the dew point temperature is determined by the intersection of dry bulb temperature and relative humidity with the dew point temperature as shown on a psychrometric chart. Figure 26-2-6 illustrates determination of the dew point temperature of 65°F when relative humidity and dry bulb temperature are known to be 60% and 75°F.

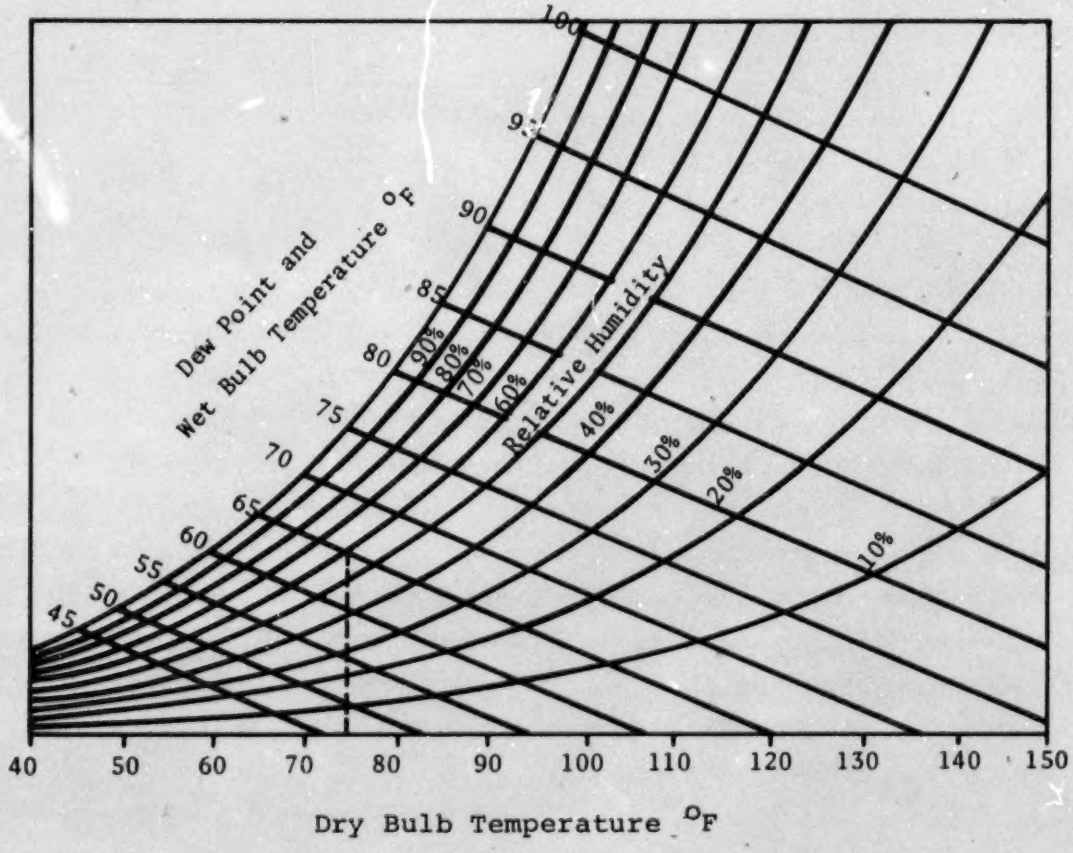


Figure 26-2-6 Psychromatic Chart

The sensitivity of pressure decay leak testing is dependent on the sensitivity and accuracy of the pressure and temperature measuring devices. Also, if very sensitive testing is required, factors are necessary to correct for volumetric expansion or contraction of the system due to pressure and temperature changes.

Since differential pressure gages can be more sensitive than absolute pressure gages, the differential pressure decay leak test method is typically more sensitive than the absolute pressure decay leak test method. The differential pressure method set-up is illustrated in Figure 26-2-7.

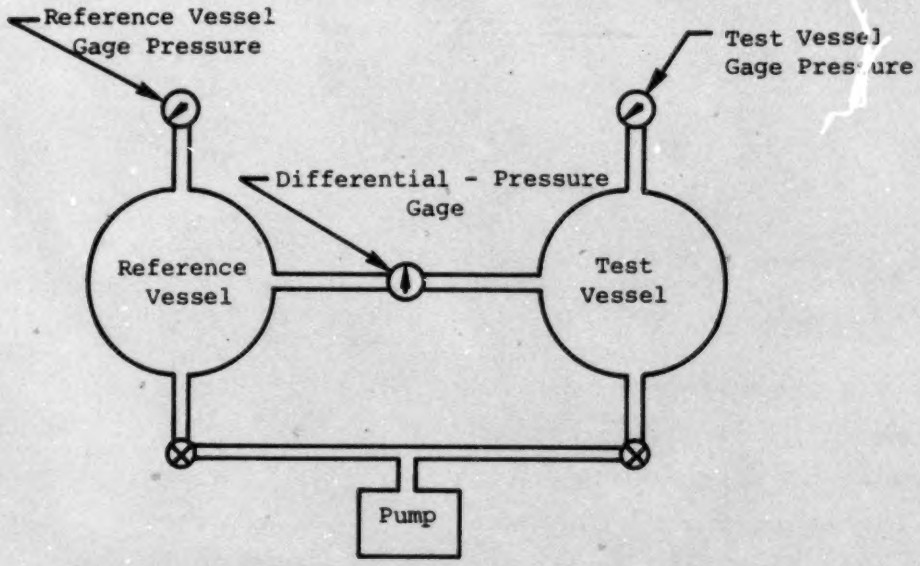


Figure 26-2-7 Simplified Diagram of Differential Pressure Leak Test

Mass Spectrometers

Mass spectrometers provide for high sensitivity leak testing. The principle component of mass spectrometers is a specially designed, evacuated tube illustrated in Figure 26-28.

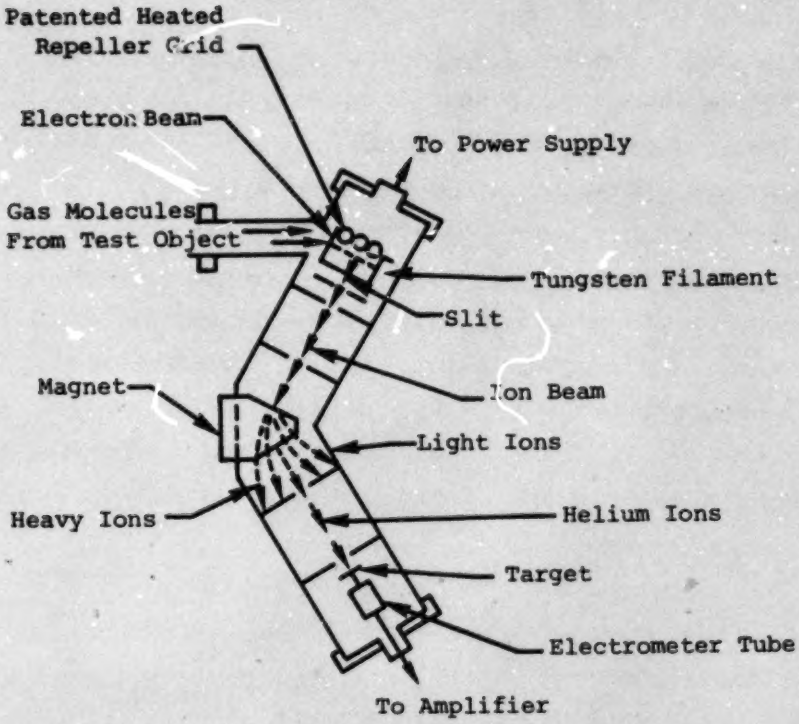


Figure 26-2-8 Mass Spectrometer "Veetube"
(Courtesy of Veeco Instruments, Inc.)

As leakage from the test object enter the mass spectrometer tube, the gases are ionized at the cathode. The positive ions accelerate toward a negatively charged collector or grid at the other end of the tube. In transversing the tube, the gas ions pass through a magnetic field which causes a deflection in the travel path of the ions which is proportional to their mass. Through adjustment of accelerating voltage or magnetic field strength, the tube is "tuned" such that only a given mass strikes the target. Those ions which hit the target cause a current flow which is directly proportional the concentration of gas ions. The current flow is amplified and displayed as leakage in atm-cc/sec.

Mass spectrometers in popular use for leak detection are permanently "tuned" to be sensitive to helium. Hence, these detectors are known as helium leak detectors or helium mass spectrometers.

Mass spectrometers are suitable for testing with system at pressure, system at vacuum and pressure-vacuum combinations. A tracer gas, such as helium must be used with mass spectrometers. Procedural techniques are described later in this module.

Visual Leak Test

Visual leak tests which are associated with nuclear power plants are almost exclusively involved with hydrostatic testing. With the system filled and pressurized with water, visual inspection looks for evidence of water leakage. Further details of this test method are given in Module 26-3, Hydrostatic Testing.

LEAK TESTING TECHNIQUES

Preparation

Regardless of the specific leak test to be performed, certain preparatory steps are essentially identical. These steps include cleanliness, sealing of openings, selection of suitable instruments, and calibration of instruments.

- cleanliness - The system to be tested is examined for cleanliness of surfaces. The surfaces must be free of contaminants, such as oil, grease, and paint, which would mask a leak. If cleaning is required using liquid cleaners, the surfaces are dried prior to commencing leak testing.

- openings - Openings in the system must be sealed to permit leak testing. Plugs, covers, sealing wax, cement or other suitable material which can be readily removed may be used. If halogen detector leak testing is to be performed, the sealing materials must be free of halogens.
- instruments - Suitable instruments are selected as required by the specific test method. Pressure gages are direct reading dial-indicating types. One pressure gage must be in view of the operator who controls system pressure. Thermocouples or resistance temperature detectors are most commonly used. For pressure decay testing, either psychrometers or hygrometers are also needed.
- calibration - Any instrument used as an integral part of the test must be calibrated to a specified accuracy. Calibration is typically performed prior to initial use of the instruments and annually thereafter.

Bubble Test Techniques

Bubble tests are performed by pressurizing the system or by using a vacuum box. In either method, temperature must be above freezing or a bubble solution having a low freezing temperature must be used.

- pressurized system bubble test - Typically air is used as the test medium although nitrogen or helium may be used. The system is pressurized to the specified pressure and pressure is held for a minimum of 15 minutes to check for gross leaks and to permit permeation of fine leaks. The bubble solution is flowed onto test surfaces with care to avoid bubble formulation due to application alone. Visual examination detects presence and location of leaks. After testing, the bubble solution is cleaned from the surfaces.

- vacuum box bubble test - The bubble solution is applied to the test surface by flowing in order to minimize bubble formation. A vacuum box is connected to a vacuum pump or air ejector and placed over the test surface. The specified vacuum is achieved and held for at least 10 seconds. Visual examination through the clear cover of the vacuum box detects presence and location of leaks.

Halogen Leak Test Technique

The hot-anode halogen diode detector is typically used for halogen leak tests. These tests are typically the pressurized gas type of test. The test requires use of a tracer gas and a calibrated leak.

The system to be tested is filled and pressurized with air which contains a tracer gas of 10% by volume. To ensure a uniform mixture of tracer gas throughout the system, the system is vented as it is filled. The tracer gas is allowed to flow for a time calculated for completely purging the system. The vents are then closed and tracer gas is added until desired pressure is reached. The tracer gas is typically Refrigerant 12 but any of the gases listed in Table 26-2-2 may be used. Detection of the tracer gas external to the system indicates presence of leaks.

A calibrated leak or standard leak, is a device containing a tracer gas which leaks at a known rate. It is used to calibrate the leak detector. The probe of the halogen diode detector is slowly passed across the orifice of the calibrated leak device to determine that the instrument reading matches that of the standard leak. Passing the probe across the orifice also determines scanning rate to be used in the system test. The scanning rate must permit detection of the value of the standard leak and it is typically

Table 26-2-2

Tracer Gases for Halogen Leak Tests

Commercial Name	Chemical Designation	Chemical Symbol
Refrigerant 11	Tricholoromonofluoromethane	CCl_3F
Refrigerant 12	Dichlorodifluoromethane	CCl_2F_2
Refrigerant 21	Dichloromonofluoromethane	$CHCl_2F$
Refrigerant 22	Chlorodifluoromethane	$CHClF_2$
Refrigerant 114	Dichlorotetrafluoroethane	$C_2Cl_2F_4$
Methylene Chloride	Dichloromethane	CH_2Cl_2

on the order of ½ inch to 1 inch per second. This calibration check is performed prior to and after leak testing and at two hour intervals during prolonged tests.

After the system is pressurized with tracer gas and the halogen detector is calibrated, the external surfaces of the system are scanned with the detector probe. Scanning speed must be equal to or less than that used at calibration. The probe tip should lightly touch the test surface as it is moved. The area being scanned must be free of air drafts. If forced ventilation causes air drafts, the ventilation must be turned off temporarily or baffles must be used to prevent drafts at the test surface.

The probe draws in air from around the test surface. At the point of leaks, the tracer gas in the leak enters the probe, becomes ionized, and thus causes current flow in proportion to the leak rate. Most halogen diode detectors provide a direct readout of leak rate and some have an audible alarm to alert the operation when tracer gas is sensed.

Whenever the shell side of shell-and-tube heat exchangers are leak tested by the halogen diode detector, each tube represents an independent leak path and must be checked. The

tubes are checked by placing the probe into each tube and monitoring for leakage for several seconds.

Helium Mass Spectrometer - Probe Method

Helium mass spectrometer leak testing with the probe method is very similar to leak testing with the halogen diode. As illustrated in Figure 26-2-9, the test system is pressurized with a tracer gas (helium) and the exterior surfaces are scanned with a probe to detect leakage. A calibrated leak is used to check the sensitivity of the detector.

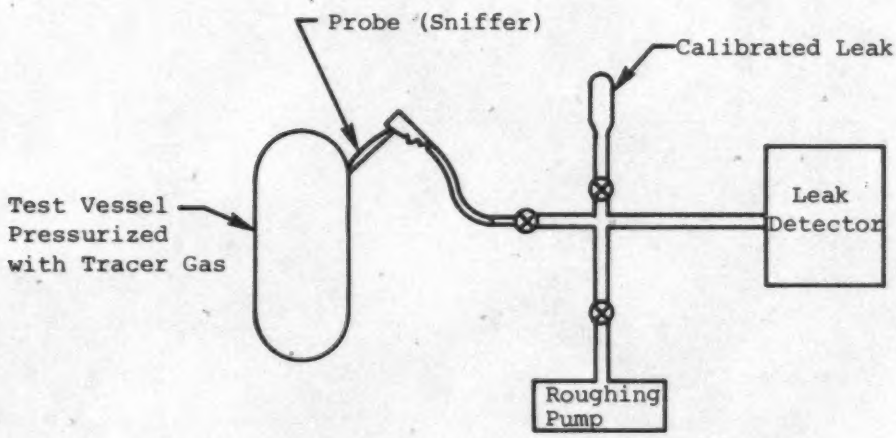


Figure 26-2-9 Connection of Probe to Detect Leaks with a Stationary Leak Detector

In helium leak testing, background readings are normally present. Small quantities of helium are in the atmosphere. Many materials absorb helium and later outgas the absorbed helium, particularly when exposed to a vacuum. Also, the helium detector has inherent electronic "noise" which contributes to background. If helium is used to test a system and then dumped in the area and testing of an adjacent system begins, the background helium will probably

mask real leakage until ventilation has adequately dispersed the dumped helium. Because of these concerns, helium should never be dumped into an area where further leak testing is to be performed. Also, the sensitivity of the helium mass spectrometer is periodically checked.

The sensitivity of the helium mass spectrometer is checked by comparing the background reading with the reading obtained from probing a standard leak. Sensitivity is stated in terms of leak rate necessary to change the reading one meter division. It is calculated by the following formula:

$$S = \frac{CL}{MR - BG}$$

Where:

S = sensitivity in leak rate per meter division
CL = calibrated leak rate
MR = meter reading of calibrated leak (division)
BG = meter reading of background (division)

The specification which governs the leak test identifies the minimum required sensitivity. For example, the ASME Boiler and Pressure Vessel Code requires a minimum sensitivity of 1×10^{-9} std cm^3/sec/division.

The probe method of helium leak testing employs the following steps:

- After equipment warm-up, the sensitivity of the detector is determined. The sensitivity check is repeated at the end of the leak test and at two hour intervals during prolonged tests.
- The system is pressurized with air containing 10% helium.
- Probe scanning speed is determined by the scanning speed used in detecting the standard leak.

- The time from probing the standard leak until the standard leak is indicated on the meter is noted.
- Test surfaces are scanned at the established speed and with the tip of the probe within 1/8 inch of the surface.

The probe method offers relatively high sensitivity. The shortest probe length possible provides best conditions. Lengths of 10 to 15 feet are typically used. When leakage is detected, a time should be allowed for purging of the probe prior to scanning other areas. This time should be greater than the reaction time noted during the calibration check.

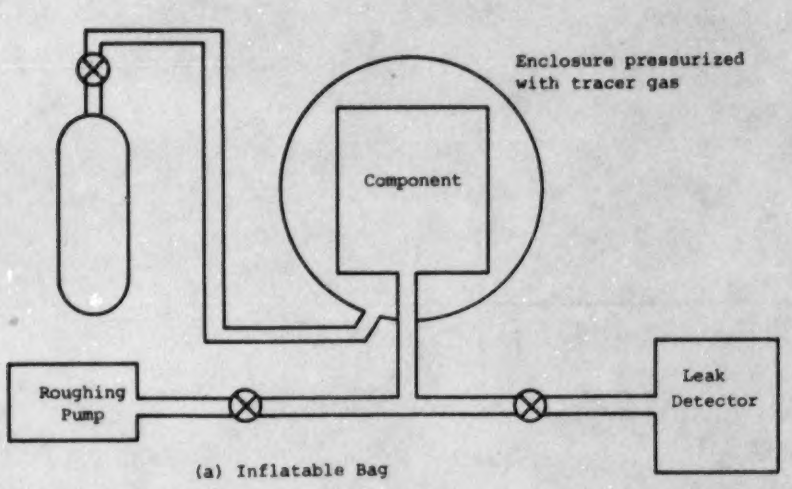
When leak testing the shell side of shell and tube heat exchangers, probing of each tube is necessary as it is in the halogen diode detector leak test.

The operator of the probe often cannot see the meter on the detector unit while probing test surfaces. This disadvantage of the probe method is offset by providing an audible indication to the operator when leakage is detected. Headsets or speakers are used for this purpose.

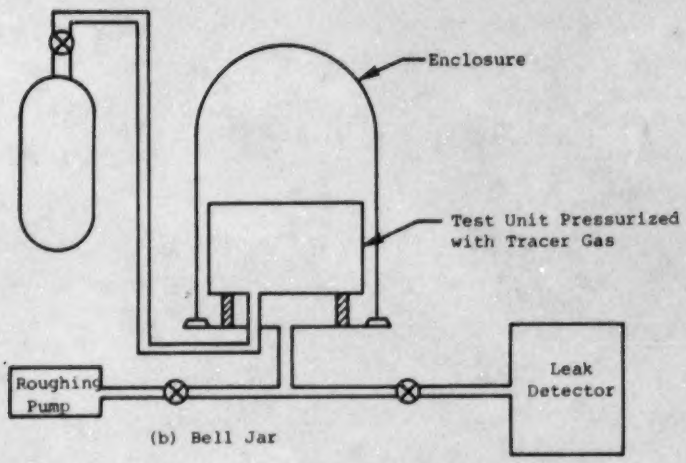
Helium Mass Spectrometer - Hood Method

Two variations of the hood method are common. One is the encapsulation of components with a flexible barrier such as a plastic bag. The leak detector is connected to the component such that a vacuum is generated within the component. The void space between the bag and the outside surfaces of the component is pressurized with tracer gas. Leakage from the outside to the inside of the component is detected. This method is typically used for large components. The other variation is by use of the bell jar. The component is placed in a bell jar and pressurized with the tracer gas. The void between the component and the bell jar is connected

to the detector such that a vacuum exists in this void. Leakage from the inside to the outside of the component is detected. This method is typically used for small components. These hood methods are illustrated in Figure 26-2-10.



(a) Inflatable Bag



(b) Bell Jar

Figure 26-2-10 Hood Method

The bell jar hood method is also readily adaptable to leak testing small, sealed components such as electronic devices. The technique for testing sealed components is termed "back pressuring." First, the sealed component is placed in the hood and the hood is pressurized with tracer gas. The pressure is allowed to stand for a time sufficient for the gas to enter the sealed component if leaks are present. Then the hood is evacuated. If gas entered the component, it will now escape through the same leaks and can be measured.

In each of the hood methods, the calibrated leak is connected in the detector sensing line at a distance from the detector as nearly as possible to the component's distance from the detector. Calculations are necessary to determine detector sensitivity, response time, measured leak rate, and actual leak rate.

Sensitivity and response time are determined by opening the standard leak to the detector, noting the time for response and calculating sensitivity in the same manner as the probe method. The sensitivity check is repeated if the set-up is changed. After the sensitivity test, the standard leak is isolated from the detector.

The leak test is performed with either the pressurized bag-evacuated component method or the pressurized component-evacuated hood method. The testing time must exceed the response time measured during the sensitivity check. The indicated leak rate on the meter is actually the sum of background and leakage and the value is dependent on whether pure helium or a percentage mixture is used as the tracer gas. Accordingly, immediately following the measurement of leakage, a series of calculations are made to determine actual leak rate. These calculations are performed as follows:

- Designate the original mass spectrometer background reading as BG, and the indicated leak rate from the test as MR.
- Depressurize the tracer gas volume but leave the line-up to the leak detector in tact.
- When the mass spectrometer reading stabilizes, designate the background reading as BG_2. (This provides a corrected background which includes inleakage from the hood from sources other than component leakage).
- Valve the standard leak to the detector, designate the meter reading as MR_2 and calculate a calibrated sensitivity as follows:

$$Sc = \frac{CL}{MR_2 - BG_2}$$

Where:

Sc = calibrated sensitivity
CL = Calibrated leak
MR_2 = reading with standard leak open to detector
BG_2 = background including inleakage from hood.

- Calculate measured leak rate as follows:

$$MLR = Sc\ (MR_1 - BG_1)$$

Where:

MLR = measured leak rate
Sc = calibrated sensitivity
MR_1 = meter reading from test of component
BG_1 = original background reading.

- Calculate actual leak rate by correcting for percentage of helium used as the tracer gas as follows:

$$ALR = \frac{MLR}{\%He} \times 100$$

Where:

ALR = actual leak rate of component

%He = percentage of helium used as the tracer gas

MLR = measured leak rate

EXAMPLE:

The helium mass spectrometer is used to leak test a component with the hood method using 10% helium in air as the tracer gas. Mass spectrometer backgrounds is 2×10^{-10} atm-cm^3/sec and the indicated leak rate is 4.7×10^{-8} atm-cm^3/sec. A calibrated leak of 6×10^{-8} atm-cm^3/sec is connected to the detector.

Given: $CL = 6 \times 10^{-8}$ atm-cm^3/sec

$BG_1 = 2 \times 10^{-10}$ atm-cm^3/sec

$MR_1 = 4.7 \times 10^{-8}$ atm-cm^3/sec

%He = 10

Solution:

- With test set up intact and tracer gas depressurized, record stabilized meter reading (BG_2). Assume reading is 5×10^{-10} atm-cm^3/sec.
- Open standard leak to the detector and record MR_2. (Assume MR_2 to equal 6.3×10^{-8} std cm^3/sec)
- calculate calibrated sensitivity:

$$Sc = \frac{CL}{MR_2 - BG_2}$$

$$= \frac{6 \times 10^{-8}}{6.3 \times 10^{-8} - 5 \times 10^{-10}} = \frac{6}{6.25} = .96$$

- calculate measured leak rate:

$$MLR = Sc\ (MR_1 - BG_1)$$
$$= .96\ (4.7 \times 10^{-8} - 2 \times 10^{-10})$$
$$= .96 \times 4.68 \times 10^{-8}$$
$$\approx 4.5 \times 10^{-8}\ \text{atm-cm}^3/\text{sec}$$

- calculate actual leak rate:

$$ALR = \frac{MLR}{\%He} \times 100$$
$$= \frac{4.5 \times 10^{-8}}{10} \times 100$$
$$= 45 \times 10^{-8}\ \text{std cm}^3/\text{sec}$$

Pressure Decay Testing Techniques

Techniques associated with pressure decay testing were previously described in the section on description of test methods. These techniques are summarized as follows:

- pressurize the system with air to the specified pressure (typically 60 psi).
- Record pressure and temperature as P_1 and T_1.
- Determine dew point temperature and ensure system is about dew point temperature.
- After specified time interval record pressure and temperature as P_2 and T_2.
- Calculate anticipated pressure (Pa) due to temperature change:

$$Pa = \frac{P_1\ T_2}{T_1}$$

- Compare anticipated pressure with measured pressure, P_2. If P_2 = Pa, there is no measurable leak. If P_2 < Pa, leaks are present.

COMMON ERRORS MADE IN LEAK TESTING

The most common errors made in leak testing are

- using too sensitive a test method
- using only one leak testing method
- not controlling the environment in the area of the test.

It is good practice to conduct leak tests in two or more stages beginning with the "gross leak" tests and graduating to the more sensitive methods. The reasons for this practice are obvious when it is seen that the sensitive methods cannot be used for gross leaks. Following this procedure, savings in time and money are achieved by testing initially for gross leaks.

The extent of controls of the environment in the vicinity of the leak tests is dependent on the test method used. If a search gas method is used, the atmosphere must be controlled to prevent contamination by the search gas which could possibly give an erroneous indication of leakage. If an acoustic type test is being used, background noise should be controlled. If small leaks are present, airborne particulate or contaminants may cause temporary plugging of the leak in system at vacuum tests.

QUALITY ASSURANCE PROVISIONS

To help ensure proper performance of leak testing, three quality assurance provisions apply. These are requirements for written procedure, personnel certification and records.

Written procedures are developed and implemented for each type of leak test. These procedures are typically prepared by Engineering and reviewed by Quality Assurance. The procedure provides to the qualified leak test technicians sufficient guidance to properly perform the test. The procedures typically provide instructions for accomplishing the following:

- Prerequisites to be met prior to commencing the test.
- Specific steps for conducting the test including system line-up, test equipment to be used, calibrations to be performed and test steps to be completed.
- Precautions to be observed while conducting the test.
- Acceptance criteria against which the leak rate is compared.
- Actions to take when acceptance criteria are not met.
- Reports of the leak test results.

Leak test technicians are trained and certified in accordance with a formal program established by each company that performs leak tests of safety related components and systems. Recommended Practice, SNT-TC-1A, which is published by the American Society for Nondestructive Testing, provides guidelines for establishing the personnel certification program. This document recommends training and experience as listed in Table 26-2-2 for two levels of certification. Level I testers are qualified to perform leak tests in accordance with written procedures. Level II is a higher qualification which equips the tester to interpret specifications governing leak testing.

Table 26-2-2
Recommended Training and Experience Minimum Levels
Training (Hours)

Leak Testing	Level I				Level II			
	BT	PCMT	MSLT	MSLT	BT	PCMT	HDLT	MSLT
*Completion with a passing grade of at least 2 years of engineering or science study at a university, college, or technical school	2	16	8	28	2	12	6	16
**High school graduation, diploma or its equivalent	2	24	12	40	4	16	8	24
***Grammar school graduation, or demonstrated proficiency, or additional training	2	96	48	NA	4	80	40	NA
	Work Time Experience (Months)							
All education levels are listed above	-Mo. 2 Hr	1½	1½	4	½	4	4	6

NA = Not Applicable.

BT = Bubble Test

PCMT = Pressure Change/Measurement Test

HDLT = Halogen Diode Leak Test

MSLT = Mass Spectrometer Leak Test

Asterisks refer to the Recommended Training Course Tables

Note 1: The training for Level II is in addition to that for Level I.

Note 2: Credit for exerpience may be gained simultaneously in two or more disciplines. The candidate must spend at least 25% of this work time on each discipline for which experience is being claimed.

Candidates who meet the established training and experience levels are certified upon successful completion of examination. The examination includes written and practical examination. The practical examination requires the candidate to demonstrate performance of the leak test.

Records are required of each leak test and of personnel certifications. With regard to leak test records, a report is generated for each component or system tested. The report identifies date of the test, name of the leak tester, leak test procedure number, and the test results.

SAFETY PRECAUTIONS

This section provides a brief review of standard safety precautions. The student/trainee should become familiar with precautions applicable to the laboratory or shops and obey them at all times. One of the basic rules of safety requires the proper behavior of every individual. Practical jokes and horseplay cannot be tolerated. The possible consequences are too high a price to pay for the small amount of humor derived.

Another basic rule requires good housekeeping practices. Care must be taken to keep the work area clean and free from oil. Clutter and slippery oil spots lead to accidents.

Refrigerant Safety

The following safety precautions are typical of those to be followed when using, storing or handling bottled refrigerants:

- Never drop cylinders or permit them to strike each other violently.

- The cap provided for valve protection must be kept on cylinders except when the cylinders are being used.
- Never use cylinders for any purpose other than their intended purpose. Do not use then as rollers, supports, etc.
- Do not tamper with the safety devices in the valves or cylinders.
- Make sure that the threads on regulators or other connections are the same as those on the cylinder valve outlets. Never force connections that do not fit.
- Never attempt to repair or alter cylinders or valves.
- Store cylinders in a cool dry place, in an upright position. (If the cylinders are exposed to excessive heat, a dangerous increase in pressure can occur.)
- Never allow R-12 to come in contact with a flame or red-hot metal. When exposed to excessively high temperatures, R-12 breaks down into phosegene gas, an extremely poisonous substance.

  (Note: Although R-12 is generally classified as non-toxic, it is poisonous in high concentrations such as might occur from excessive R-12 leakage in a confined or poorly ventilated space. If a person should be overcome by R-12, remove them immediately to a well-ventilated place and get medical attention at once. Watch their breathing, if the person is not breathing, begin artificial respiration.)

Industrial Gas Safety

All compressed gases are dangerous if improperly handled. Some of the more important precautions pertaining to industrial gases in addition to those listed for the refrigerant gases are:

- Constantly inspect for leaks and tighten or replace leaking fittings, hoses, etc.
- Watch all temperature and pressure indications. Small changes in temperature can result in large changes in pressure.
- Make sure hoses and fittings are always tight; do not interchange fittings or hoses with similar equipment for other gases.
- Close the valves and replace outlet caps when cylinders are not in use.

Appendix 26-2-1
Leak Rate Conversion Factors

To Convert	To	Multiply Column 1 By
STD·cm^3/s[a]	Micron liters/s	7.60×10^{-2}
	Micron ft^3/h	9.66×10^{-4}
	torr·liters/s	7.60×10^{-1}
	≡1 cm^3/day	1.16×10^{-3}
	≡1 cm^3/year	3.16×10^{-8}
Micron·liters/s	STD·cm^3/s	1.32×10^{-3}
	Micron ft^3/s	1.27×10^{-2}
	torr·liters/s	1.00×10^{-3}
torr·liter/s	STD·cm^3/s	1.32
	Micron liters/s	1.00×10^{-3}
	Micron ft^3/s	1.27×10^{-5}
Micron ft^3/s	STD·cm^3/s	1.04×10^{-5}
	Micron liters/s	7.87×10^{-3}
	torr·liters/s	7.87×10^{-6}

Example: Given: 0.1 Micron ft^3/s
Find: Number STD·cm^3/s
Solution: $0.1 \times 1.04 \times 10^{-5}$ STD·cm^3/s 1.04×10^{-6}

@ STD·cm^3/s = atm·cm^3/s.

Appendix 26-2-2
Useful Factors in Leak Testing Work

1 atmosphere (atm)	= 14.7 pounds per square inch absolute (psia) = 760 millimeters of mercury (mm Hg) = 7.6×10^5 microns
1 micron	= 1×10^{-8} meters of mercury (m Hg) = 1×10^{-3} mm Hg
1 torr	= 1/760 of a standard atmosphere
1 millitorr (mtorr)	= 1×10^{-3} torr
1 microtorr (μtorr)	= 1×10^{-6} torr
1 cubic foot (ft^3)	= 28,320 cm^3 = 28.32 liters = 7.48 gal
1 cubic inch ($in.^3$)	= 16.4 cm^3
1 liter	= 61.0 $in.^3$ = 0.0353 ft^3 = 1.0567 U.S. qt
Seconds in 1 year	= 31,563,000 s/year = 3.16×10^7 s/year
Percentage of helium in air	= 0.0004 percent
Partial pressure of helium in air at Standard Temperature Pressure (STP)	= 0.00304 mm Hg = 3.04 microns

EXERCISES

The following exercises serve to reinforce the material covered in this module.

1. Perform the Bubble Test on a test bell jar equipped with a vent valve as described in the Procedures section of this module. The Materials required for this test are also listed in the following section.

2. Perform the Helium Mass Spectrometer Test as outlined in the Procedures section of this module. The Materials required for this exercise are also listed in the following section.

3. Define the following terms:
   a. Leak
   b. Leakage
   c. Leak rate

4. Briefly describe the three sets of conditions under which leak testing may be accomplished.

5. Give three general reasons for making leak tests on systems or components.

6. Compare the following test methods as to relative sensitivity.
   a. Bubble Test
   b. Pressure Change
   c. Halogen Diode Detector
   d. Helium Mass Spectrometer

7. Indicate whether each of the following statements are true or false:

____ a. Leak tests were first performed in 1934.

____ b. Vacuum chambers used in leak testing are leak-free.

____ c. The halide torch changes color in the presence of halides.

____ d. Using the bubble test, the leak rate can be determined by timing the length of time required to form a standard bubble.

____ e. The helium mass spectrometer can be used on a system at pressure as well as a system at a vacuum.

Answer the following multiple choice questions #8 and #9.

8. A halogen diode detector will detect compounds containing
   a. Fluroine
   b. Chlorine
   c. Bromine
   d. All of the above

9. Helium mass spectrometers detect
   a. Hydrogen
   b. Helium
   c. Hafnium
   d. None of the above

10 Describe the operation of the Halogen Diode Detector.

11. Why should temperature be held above dew point temperature during pressure decay leak testing?

12. Why is differential pressure decay leak testing generally more sensitive then absolute pressure decay leak testing?

13. Describe the operation of a mass spectrometer tube.

14. Why is surface cleanliness important to leak testing?

15. Describe the pressurized system bubble test.

16. Describe the vacuum box bubble test.

17. Describe the pressurized system halogen diode leak test.

18. Describe the hood method of helium mass spectrometer leak detection using an inflatable bag.

19. Describe the pressure decay leak test.

MATERIALS

The following equipment and materials are required to support this module:

A. Bubble Test
   1. Air compressor, air pump or other compressed air source
   2. Bubble solution
   3. Piping, tubing, valves, fittings and adapters necessary to construct a small enclosed system with a test connection
   4. Pressure gage (0-50 psi range)
   5. Assorted wrenches for tightening fittings and adaptors.
   6. Bell Jar or other test chamber fitted for a pressure test.

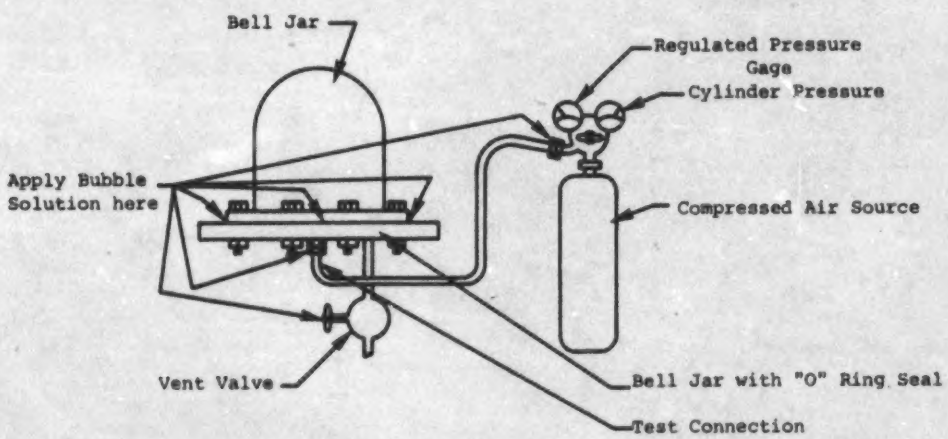
B. Helium Mass Spectrometer - Probe Method

1. Helium Gas Bottle
2. Calibrated Leak in range of 1×10^{-6} to 1×10^{-10} atm-cc/sec
3. Helium mass spectrometer
4. Probe, hose, and fittings
5. Assorted wrenches for tightening hose connections
6. Supplier's equipment manual for the helium mass spectrometer.

PROCEDURES

The following procedures are in reference to Exercise #1 and #2 of this module. If facilities are unavailable for these tests, a tour of a testing laboratory may be substituted for these particular exercises.

1. Bubble Test Procedure
   a. Assemble a closed system similar to that in the following sketch:



b. Connect the compressed air source to the test connection, close the vent valve and pressurize the system to 5 psi.

c. Observe the pressure gage for 1 minute. If pressure decay occurs, recheck all connections for tightness. If pressure still decays, accomplish steps g through k to execute repairs.

d. Pressurize the system to 30 psi.

e. After a 15 minute time at 30 psi, apply the bubble solution to all connections and to valve stems.

f. Observe for evidence of leakage. Mark each area of leakage. If there is no leakage, go to step l. If there is leakage, go to step g.

g. Slowly open the vent valve and depressurize the system.

h. Ensure vent valve is fully open and pressure gage indicates that the system is depressurized.

i. Disconnect those connections which were marked as leak sources and visually inspect them for potential causes of leaks. Look for dirt, broken threads, missing or damaged "O" rings or seals.

j. Repair or replace the leaking components and reassemble the enclosed system.

k. Repeat steps b through f.

l. Slowly open the vent valve to depressurize the system.

m. Open vent valve fully. Determine from the instructor if the system is to be left in-tact or dismantled.

2. Helium Mass Spectrometer - Probe Method Test

a. Turn power on to the helium mass spectrometer. Allow warm-up time as recommended by the manufacturer prior to performing step c.

b. Connect the sniffer probe to the helium mass spectrometer with appropriate hose and fittings in accordance with the supplier's manual.

c. Determine detector sensitivity as follows:
   - select detector range to the range in which a background reading occurs.
   - record background reading.
   - set detector range to power of ten as for the standard leak.
   - probe standard leak and record reading.
   - calculate sensitivity: $S = \frac{CL}{MR - BG}$

   (Note: sensitivity should be about 1×10^{-9} atm -cc/sec/div. Consult supplier's manual for sensitivity value and method of correction).

d. Scan the standard leak with the probe to determine scanning speed and response time.

e. Probe a filled helium gas bottle.

f. Record measured leak rate.

DATA TABLE

None.

REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Section V, Article 10, Leak Testing, American Society of Mechanical Engineers, New York, N.Y.

ASTM Standards, American Society for Testing and Materials, New York, N.Y.

- E 425, Standard Definition of Terms Relating to Leak Testing (Also ASME Se-425)
- E 432, Selection of a Leak Testing Method (Also ASME SE-432)
- E 479, Preparation of a Leak Testing Specification (Also ASME SE-479)
- E 498, Leaks Using the Mass Spectrometer Leak Detector or Residual Gas Analyzer in the Tracer Probe Mode
- E 499, Leaks Using the Mass Spectrometer Leak Detector in the Detector Probe Mode
- E 515, Leaks Using Bubble Emission Techniques

NASA SP-5113, Nondestructive Testing, Chapter 9, Leak Testing, Superintendent of Documents, Government Printing Office, Washington, D.C. 20402 (Stock No. 3300-00471)

ASM, Metals Handbook Volume II, Nondestructive Testing and Quality Control, American Society for Metals, Metals Park, Ohio 44073

ASNT, Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing, SNT-TC-1A, American Society for Nondestructive Testing, New York, N.Y.

TEST

Essay

Answer the following questions as indicated.

1. a. Describe three sets of conditions under which leak testing may be accomplished.
   b. Give three general reasons for performing leak tests on systems or components.
   c. Name three fundamental conditions which promote fluid flow across system boundaries and briefly describe how each condition

2. Define or briefly describe the following:
   a. Leak
   b. Leakage
   c. Leak rate
   d. Bubble Test
   e. Pressure Change (in leak detection)
   f. Halogen Diode Detection
   g. Helium Mass Spectrometer

Answer the following questions as either true or false:

3. Vacuum chambers used in leak testing have "zero leakage". _____

4. The term leak refers to the discontinuity or passage through which a fluid flows or permeates. _____

5. Leakage refers to the fluid that has escaped through the leak. _____

6. Leak testing of systems or components is necessary for all of the following reasons: _____
   a. Prevent loss of contents
   b. Prevent containment of the working fluid

c. Detection of the unreliable components
d. Assure the maintenance of pressure differentials

7. The relative sensitivity of the following leak test methods are in the order as listed: _____
   a. Bubble Test
   b. Pressure Test
   c. Halogen Diode Detector
   d. Helium Mass Spectrometer

8. Halogen torches are not effective for measuring leak rate, cannot be used in an explosive atmosphere and when used to detect refrigerant leaks may give false indication of the leak location. _____

9. Helium mass spectrometers will also detect hydrogen, hafnium and chlorine. _____

10. The halogen diode detector works on the principle that ionized halogen atoms can produce a current that can be detected by electronic circuitry. _____

11. Pressure loss leak testing and differential pressure testing rely on the ideal gas laws. The ideal gas laws relate pressure, temperate and volume. _____

12. Water vapor in a test medium can affect the accuracy of the results. _____

13. Mass spectrometers provide high sensitivity leak testing. The gas ions are accelerated by a voltage or magnetic field and "tuned" so that a given mass strikes a target. The current flow caused in the _____

the electronic circuitry is directly proportional to the concentration of gas ions and may be appropriately displayed as a leakage rate.

14. Unclean surfaces can mask leaks and prevent proper _____ leak detection.

15. The pressure decay leak test uses air at dew point _____ temperature and is accomplished by recording differences in ambient and dew point temperatures after successive temperature readings. The pressure remains constant during this test.